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# A safe space of rural areas in the context of the occurrence of extreme weather events—A case study covering a part of the Euroregion Baltic

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ABSTRACT

Ongoing climate change was first noticed by the public a few decades ago. The factual occurrence of such a change and its impact on the space were confirmed by both results of scientific research and economic assessments carried out for a variety of economic purposes. The economic sectors whose activities are based on natural weather conditions are most vulnerable to the effects of ongoing climate change. An increase in the number of extreme events, and primarily of their effects, are deeply felt by, primarily, the agricultural community. The study focused on the agricultural sector involved in crop cultivation within a part of the Euroregion Baltic. For analyses, statements on financial losses in agriculture, suffered in the years 2010–2014 and caused by extreme weather events (*inter alia* rainstorm, hail, cyclones, lightning strike, flood, spring frost, drought, the negative effects of over-wintering of crops), were used. By applying the theory of scale-free networks, a network of relationships was constructed, which allowed the authors to indicate sensitive places vulnerable to financial consequences of such events in rural areas.

The European Union policy which also embraces the fragment of the part of the Euroregion Baltic under study aims at broadening the range of policy instruments which are to affect changes to land use patterns in order to find the balance between the outcomes of agricultural production and the adverse effects brought about by this production to natural ecosystems. This direction of activities is also aimed at preventing the effects of climate change. The constructed *scale-free* network model indicated that not all agricultural areas are equally affected by the financial effects of the occurrence of extreme events. An analysis enabled the indication of the most vulnerable (sensitive) locations, the so-called *hubs*, while the investigated topology of the system leads to the conclusion that financial losses in the current sensitive locations may increase to an unimaginable level. Knowledge of the nature of the system, however, allows one to affect its evolution. Targeting of the European Union policy instruments toward the areas most affected by the consequences of extreme weather events will make agricultural producers less vulnerable to them and strengthen the farmer community's trust in the expected financial results of the farm work.

## 1. Introduction

Climate change is currently one of the key environmental, social, economic and political problems in numerous countries. The effects of this change, occurring over the last few decades, intensify, and therefore have become an object of interest to governments and the international community.

The climate of the Earth has changed many times due to the fluctuations in solar radiation, changes to the parameters of the Earth's orbit around the Sun, changes to the composition of the Earth's atmosphere, and the properties of the Earth's surface (Kundzewicz and Juda-Rezler, 2010). According to the report of the *Intergovernmental Panel on Climate Change*, climate warming over the recent decades is clear because the atmosphere and the ocean are heated, the amount of snow and ice has decreased, and both the sea level and the greenhouse gases concentration have risen (IPCC, 2013). This fact is also confirmed by scientific research involving the observation of the elements of atmosphere using the latest methods (Rahman, 2016; Li et al., 2015; Van Malderen et al., 2014; Guerova et al., 2016; Khodayar et al., 2016). Humans also actively participate in the climate change through population growth as well as economic, socio-political, cultural, religious, scientific and technological factors which bring about changes in ecosystems (Nelson et al., 2006; Martinez-Harms et al., 2017).

The existence of humans is determined by a variety of ecosystems (agroecosystems, forest, aquatic, and natural ecosystems, etc.) yet humans systematically change them with their existence, leading to their

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degradation. In every region of the world, plants, animals, and ecosystems are adapted to the prevailing climatic conditions. When these conditions change, the plants and animals present will be impacted, some will become less productive, or even disappear (Gordon et al., 2010; Harrison et al., 2010; FAO, 2016). Changes in ecosystems occur due to the complex interaction between mutual relationships between people and their surroundings, when they try to satisfy their basic needs and improve their well-being (Nelson et al., 2006). Agricultural ecosystems may also act to the detriment of natural ecosystems (e.g. plant diseases, crop pests, water use, soil impoverishment, spread of undesirable species), reducing their efficiency or increasing production and management costs (Zhang et al., 2007). Certain changes in ecosystems are difficult to predict e.g. the effect of a certain climatic change on a whole ecosystem, because each element will react differently and interact with the other. The absence of internal mechanisms controlling the relationships between the costs borne by the environment and the land use and management (Bryan, 2013; Lant et al., 2008) is the main cause of the changes occurring in natural ecosystems. The concept of ecosystem service includes a range of provisioning (e.g., food, fresh water, and bioenergy), regulating (e.g., climate, erosion, and pests), supporting (e.g., biogeochemical cycling, biodiversity/habitat), and cultural (e.g., recreation and education) services (Power, 2010; Bryan, 2013). However, ecosystem service does not remedy the adverse effects of agricultural production which influence the balance between the supplies of different ecosystem goods and services (Wiggering et al., 2016). This creates additional hazards to agricultural productions, resulting from climate change, which directly translate into hazards to food security and feeding people. This particularly concerns social groups directly dependent on agriculture in terms of livelihood. Such hazards may also affect food security and feeding remote populations through the volatility of prices and the distortion of trade. According to the *Food and Agriculture Organization of the United Nations* (FAO, 2016), climate change affect rural areas and the agricultural production in many aspects (Fig. 1). A range of physical, biological and biophysical impacts bear on ecosystems and agroecosystems, translating into impacts on agricultural production. This has quantity, quality and price effects, with impacts on the income of farm households and on purchasing power of non-farm households. All four dimensions of food security and nutrition are impacted by these effects *(*FAO, 2016*)*.

Restoring natural ecosystems through changes to the pattern of land use and management is currently the global priority *(*Ehrlich et al., 2012; Foley et al., 2011) as they are able to counteract the effects of human activities (climate change). Recommendations for food production include a recommendation of crop management − this particularly concerns the dates of sowing cereals, the selection of a variety, and a change to the duration of irrigation. According to Müller and Elliott (2015), adaptive changes to crop management are likely to improve the productivity by approx. 7–15%, although these results depend greatly on the region and type of crops. An increase in efficiency of limited water resources is another important aspect of creating the flexibility of agricultural farms in the context of climate change, therefore the management of shortages and surpluses is an important item of adaptation. New cultivation practices enable a reduction in the exposure of the topsoil to the impact of climate, an increase in evaporation, an increase in the characteristics of soil humidity, and a reduction in the sensitivity to drought and heat. Increasing the diversity in production systems is also of importance. This can take various forms, for example: a combination of various types of production, e.g. forestry, crop and animal production; an increase in the number of various species, populations, varieties or breeds; and an increase in the use of a genetically diverse material. Such a strategy aims to minimise risks in the future. Finding ways to combine diversity strategies is one of the main challenges of the future (FAO, 2015). In addition, according to Jones and Thornton (2009), in certain regions, flexible transition between crop and animal production will be of key importance in the adaptation strategy.

Policy-makers, having noticed the problem of imbalance, are also developing market policy instruments (including financial incentives) for the provision of ecosystem service (Bryan and Crossman, 2013). For instance, documents concerning Common Agricultural Policy in force in the EU and in the part of the Euroregion Baltic under study set out the principles of the so-called cross-compliance as well as agri-environment-climate packages in which the amounts of obtained payments are linked with the fulfillment of specific requirements by beneficiaries. These requirements are primarily supposed to counteract soil erosion, limit the degradation of organic matter, to counteract changes to the soil structure, and preserve and protect plant and animal habitats as well as water. Proposed the introduction in rural areas of (1) buffer zones (tree and bush covers) on agricultural land at a distance of 5–20 m from the edge of water courses, drainage ditches, channels, lakes and water reservoirs (with an area of up to 50 ha), water intakes, and the areas of marine coastal waters; (2) field woodlots and shrubs, also along transport (including agricultural transport) routes; (3) woodlot strips conducted along contour lines, and surface woodlots at locations vulnerable to erosion; (4) the maintenance of vegetation cover, stubble fields, forecrop post-harvest remnants, and mulch at 30% of the area of arable land in farms located in areas exposed to water erosion; (5) a ban on the cultivation of plants requiring the maintenance of ridges along the slope in arable land situated on slopes of over 20°; these areas must be used for the cultivation of perennial plants, with a vegetation cover or litter in interrows; (6) a ban on grassland burning (grass, post-harvest remnants, etc.) which will help maintain an appropriate level of organic matter; (7) a ban on trimming hedges and trees in the periods of bird hatching and rearing, and on the destruction of natural monuments and ditches up to 2 m in width, which will ensure the maintenance of agricultural landscape features; (8) the protection and conservation of garden ponds within a farm with a total area of up to 100 $m^2$; (9) a ban on the destruction of habitats and refuges which are areas of reproduction, rearing, resting, migration and preying of birds under protection within Natura 2000 sites; (10) a ban on the erection of structures, installations and devices without permit within Natura 2000 sites; (11) compliance with the rules of fertilisation on steeply sloping, water-logged, flooded, frozen or snow covered areas; (12) the proper application of plant protection products and biocides; (13) the maintenance of an appropriate level of greenness through the diversification of crops; the maintenance of permanent pasture on an appropriate surface; the maintenance of pro-environmental areas in agricultural farms with an area of over 15 ha of arable land (fallow areas, elements of agricultural landscape, hedges, trees planted in groups, tree strips, field margins, water holes, shrubs along drainage ditches and watercourses, under-sowing of grass in the main crop, or mixtures made of 2 groups of indicated plants (ZWZ, 2014).

Each financial incentive can influence multiple land uses, and each land use can affect multiple ecosystem services (Bryan and Crossman, 2013). According to Bryan (2013), when changing agricultural land use back to natural ecosystems through restoration, trade-offs have been found between achieving salinity and biodiversity objectives (Maron and Cockfield, 2008), and between carbon sequestration and a range of other services including biodiversity (Crossman et al., 2011), food (Nelson et al., 2010; Paterson and Bryan, 2012), and water (Chisholm, 2010).

Previous research addressing the issue of climate change focus on many aspects related to climate change. For example, many studies have explored the local and regional economic impacts of specific events, such as tropical cyclones, floods, earthquakes, heat waves, and wild fires (Pielke, 2007; Zhang et al., 2009; Okuyama and Chang, 2004). Quantitative scenario analysis has been widely applied at multiple scales and has addressed multiple issues (Alcamo et al., 2008; Rothman, 2008; Rounsevell et al., 2014; Nakicenovic et al., 2014; Bryan et al., 2016) some of them are targeted, sector-wise, towards agriculture and land use (Golub et al., 2012; Havlik et al., 2011; Thomson et al., 2010; Van Der Werf and Peterson, 2009). These analyses, containing

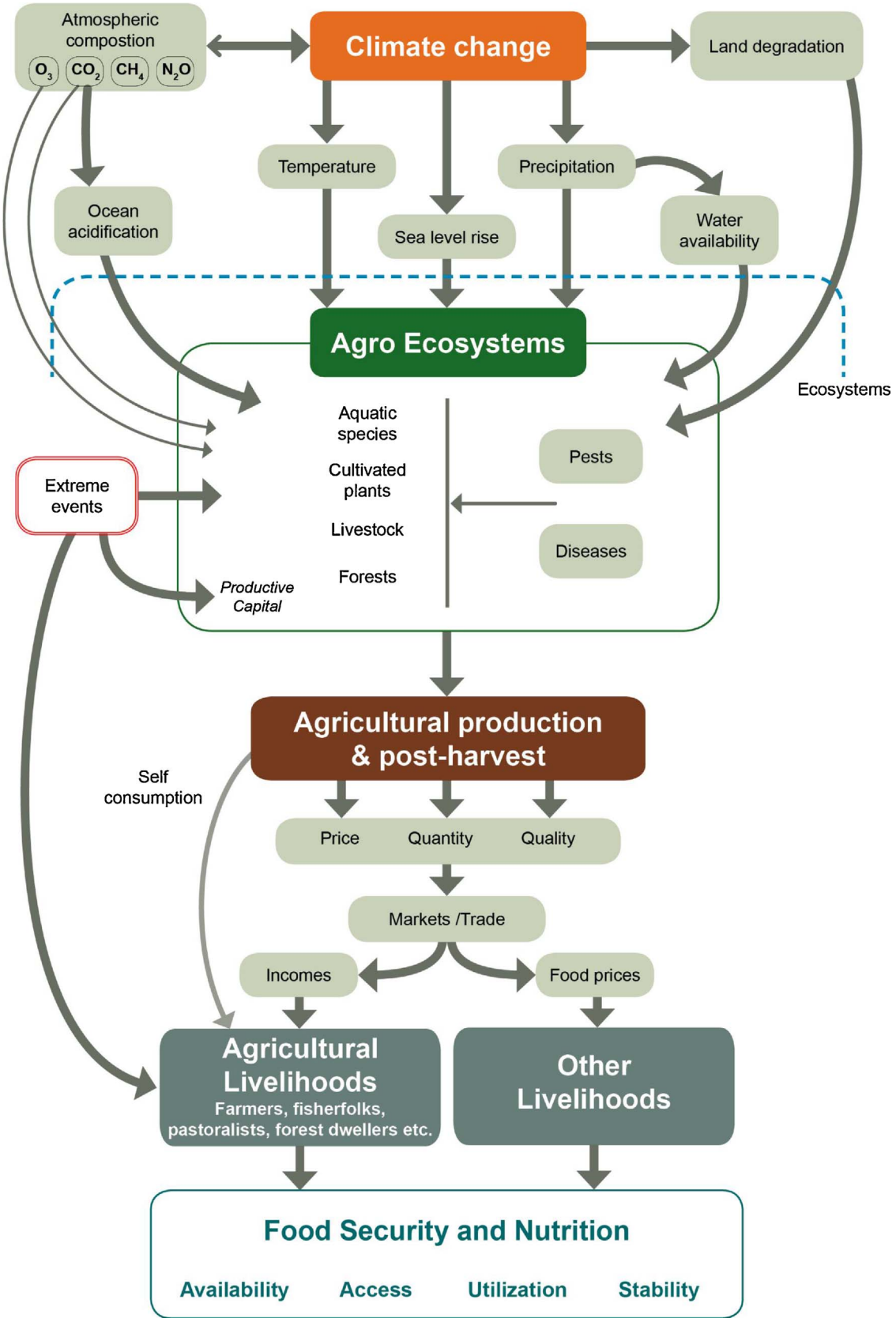



**Fig. 1.** Schematic representation of the cascading effects of climate change impacts on food security and nutrition.
Source: FAO (2016).

future influence of climate, population, policy, market forces, technology, and affluence on land-use and sustainability enable one to notice that the effects of global changes will affect all nations in ways that are impossible to predict (Bryan et al., 2016). However, global climate change most severely affect local communities, therefore studies and analyses should be related to a local scale with high spatial resolution (Swart et al., 2009; Measham et al., 2011; Adger and Kelly 1999; Cutter et al., 2000). The presented article fills the gaps as regards the integrated effect of many extreme events (in example 8 under study) on a single unit (commune).

The aim of the study is to analyse the type of and the scale of the occurrence of weather events not classified as a natural disaster (extreme events) in agricultural areas in a part of the Euroregion Baltic. The data included in the analysis concerned losses in the agricultural production in the years 2010–2014. The selection of a study area was based on the key dependence of the economy of a region on natural weather conditions. 100 municipalities and urban-and-rural communes (in the part used for agricultural purposes) were investigated. The issue of the occurrence of climate change and extreme weather events is a subject addressed in many areas of science. The studied and analysed case studies at the local level affect decisions related to the purchase of land for agricultural production, planning of the choice of the line of agricultural production, an opportunity to select appropriate adaptation measures, and the identification of "sensitive areas". Rural areas are where food is produced. Their main task is to ensure the continuous supply of food products, to satisfy the needs related to recreation, biodiversity, water supply, and carbon dioxide sequestration. Satisfying these needs requires the implementation of targeted policy instruments in order to encourage agricultural producers and other entities making use of rural areas to perform actions restoring natural ecosystems. In the most vulnerable, "sensitive" areas, these instruments should be implemented as a priority.

## 2. Theoretical background

### 2.1. Study area

The area of the study − a part of the Euroregion Baltic (the Region of Warmia and Mazury) is located within the Baltic shorelands and lake districts spreading from Scandinavia, through north-western Russia, Estonia, Latvia, Lithuania, northern Belarus, and northern Poland to northern Germany. It is the so called Baltic Green Belt − an important part of the European system of natural interconnections. In the north-south direction, the region stretches for 146 km, while in the east-west direction, for 240 km. The geographical coordinates of the: most northward point – 54°27′11″ N, most southward point – 53°08′27″ N, most westward point – 19°07′39″ E, and the most eastward point – 22°47′07″ E.

The area under study offers wide possibilities for agricultural production (see Table 1), however natural conditions make the unit costs of agricultural production high and the profitability lower than in other regions of the country. 83.25% of agricultural lands in the area of the study is located within less-favored areas (LFAs). Farmland is assessed in view of soil quality, climate, landform and hydrological conditions, as well as social and economic factors such as employment in agriculture and income per farming unit. The area under study covered an area of 994 thousand ha. Only agricultural land under cultivation and the areas used for pasturing were taken into account, while forest areas, water bodies and built-up areas were excluded. The area concerned is administratively divided into communes which have become the reference units. In 60% of municipalities, in the years 2010–2014, financial losses were noted due to the occurrence of extreme weather events. Statistical data for the study were obtained from the Voivodeship Agricultural Advisory Centre (unpublished data).

**Table 1**
Characteristics of the area under study (CSO, 2016).

| Item | Feature | Description |
|---|---|---|
| 1 | Area | 241.73 km$^2$ |
| 2 | Population density | 59 persons/km$^2$ |
| 3 | Number of agricultural farms | 47,164 |
| 4 | The area of agricultural land | 994,569 ha |
| 5 | The area of agricultural land under crops | 608,740 ha |
| | Structure: | |
| 6 | agricultural land | 55.1% |
| 7 | woodland | 32.1% |
| 8 | lands under water bodies | 5.7% |
| 9 | urbanised and developed land | 3.6% |
| 10 | the rest | 3.5% |
| 11 | the areas of high natural value | 46.3% |
| 12 | less-favoured areas | 83.25% |

### 2.2. Extreme events

Events caused by climate change pose a threat to the social and economic development of many countries (Paluck et al., 2015; Goulder and Pizer, 2006). Over the last decades, scientists also noted an increase in the number of natural disasters caused by the climate change (Kundzewicz et al., 2006), and this fact is confirmed by statistics in the terms of the financial consequences (Fig. 2) they bring about.

In general, three criteria determine as to whether or not a particular phenomenon may be regarded as extreme, namely: the rarity of occurrence, intensity, and the extent of the loss caused (Beniston et al., 2007).

The International Disaster Database (EM-DAT) gathers information on natural disasters on all continents according to the following criteria: (1) ten (10) or more people reported killed; (2) hundred (100) or more people reported affected; (3) declaration of a state of emergency; (4) call for international assistance (Guha-Sapir et al., 2017www.emdat.be). The scale of the effects brought about by an event is the determinant of its inclusion in the database. In Polish legislation, natural disasters are events which may be caused by both natural events (e.g. meteorological, climatic, geographical, hydrological, etc.) and technical events (industrial accidents, transport accidents, etc.) (Act of 18 April 2002 on the state of natural disaster). An important factor which characterises these events is the effects considered in terms of a hazard to life or health of a large number of people, and the damage to property or the environment over a large area, as well as the provided assistance and protection when applying extraordinary measures, in the cooperation of various bodies and institutions, specialised services and groups operating under a single management.

The appearance of weather events of varying severity have affect the agricultural production. These are not always natural disasters (Fig. 3) but rather extreme events. A group of such events has a significant impact on the natural environment, the income earned, or psychological well-being of rural community. Information on the effects of local extreme events is most frequently recorded only in local statistics, and not in international ones. Extreme events, when occurring in a specific location, reveal the picture of the actual and permanent farmers' struggle with the changing weather conditions affecting the agricultural production. According to Albeverio et al. (2006), defining the notion of an "extreme event" is not easy, as the general understanding of this term differs for various people and institutions such as insurance companies, politicians, journalists, or scientists. In general parlance, the impact of extreme events is determined by identifying the intensity of the impact of an event, and the frequency of its occurrence, and due to this particular attribute they can be compared with natural disasters. However, scientists also recognise an element associated with deviations in a series of measurements, similar to an extremity, and the seeming uniqueness of such events. Fig. 5 shows that extreme events may be a part of natural disasters but they also may have a local nature

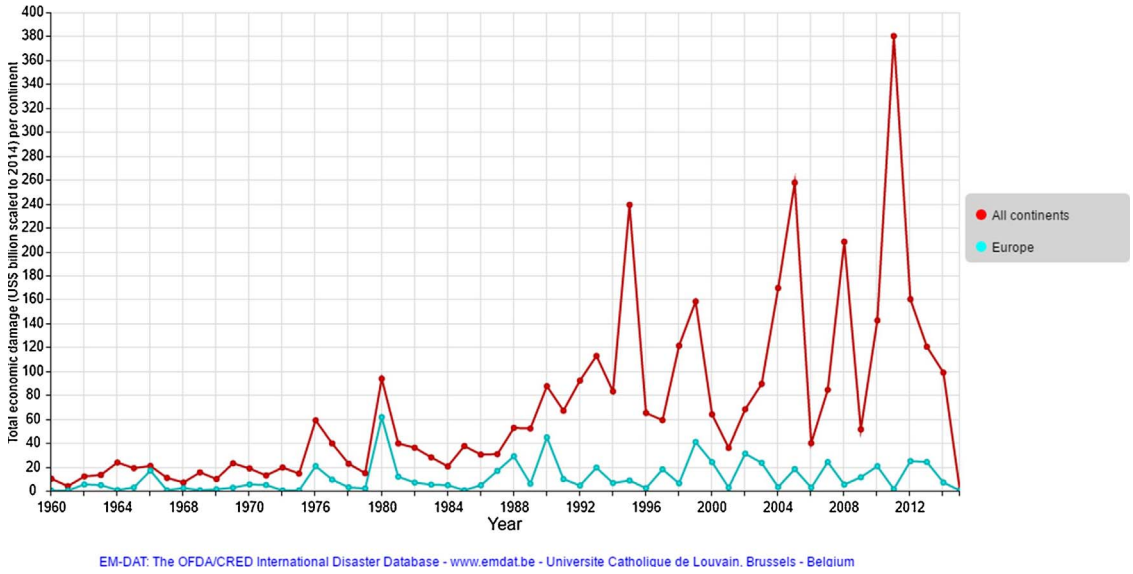

Total economic damage (US$ billion scaled to 2014) per continent
Year
All continents
Europe
EM-DAT: The OFDA/CRED International Disaster Database - www.emdat.be - Universite Catholique de Louvain, Brussels - Belgium

**Fig. 2.** Financial losses due to the occurrence of extreme weather events, scaled in relation to 2014, in the years 1960–2014.
Source: own study with Guha-Sapir et al., 2017www.emdat.be.

as, in a specific location, they may possess extreme and unique attributes. Extreme events, similarly to natural disasters, affect and contribute to the following aspects: budget planning (loans, insurance), a reduction in future income (product prices, soil erosion, low quality of pastures), a reduction in investments in the means of production, and the development of modern technologies in an agricultural farm (FAO, 2016).

Financial losses in agricultural cultivation were noted for 60% of municipalities/communes within the area under study. A level was adopted for the losses noted for one unit (an agricultural farm), resulting from the assumptions as regards the launching of a programme of assistance for agricultural producers, and it amounted to 260 US$. The amount of losses in particular municipalities/communes varied significantly from approx. 1200 US$ in the municipality of Frombork to almost 3.6 million USD in the municipality of Biskupiec (1 US$ = 3.87 PLN). Table 2 summarises financial losses with account taken of the years of analysis and the type of event.

The greatest financial losses were caused by: the negative effects of over-wintering of crops – 27.4%; drought – 25.2%; hail – 20.5%; torrential rains – 13.2%; spring ground frosts – 9.0%; lightning strikes – 2.6%; cyclones – 1.3%; and flood – 0.8% (see Table 2). Figs. 4–11 show particular events along with their location in municipalities/communes affected by losses.

Extreme weather events occurring in the area under study and resulting in financial losses in agricultural crops have characteristics associated with the location. Crops in the northern part of the area study (the Region of Warmia and Mazury) are destroyed by adverse effects of over-wintering, hail, and torrential rains. Floods are extremely rare events in this part of the country. The terrain of the region under study is lowland in nature, and a significant number of water bodies (lakes, ponds, and water holes) and rivers connecting them are located there. Excess rainwater is discharged between those water bodies and courses. In the southern part of the region under study, the events of drought and hail occur most often, while cyclones, lightning strikes and spring ground frosts occur rather rarely.

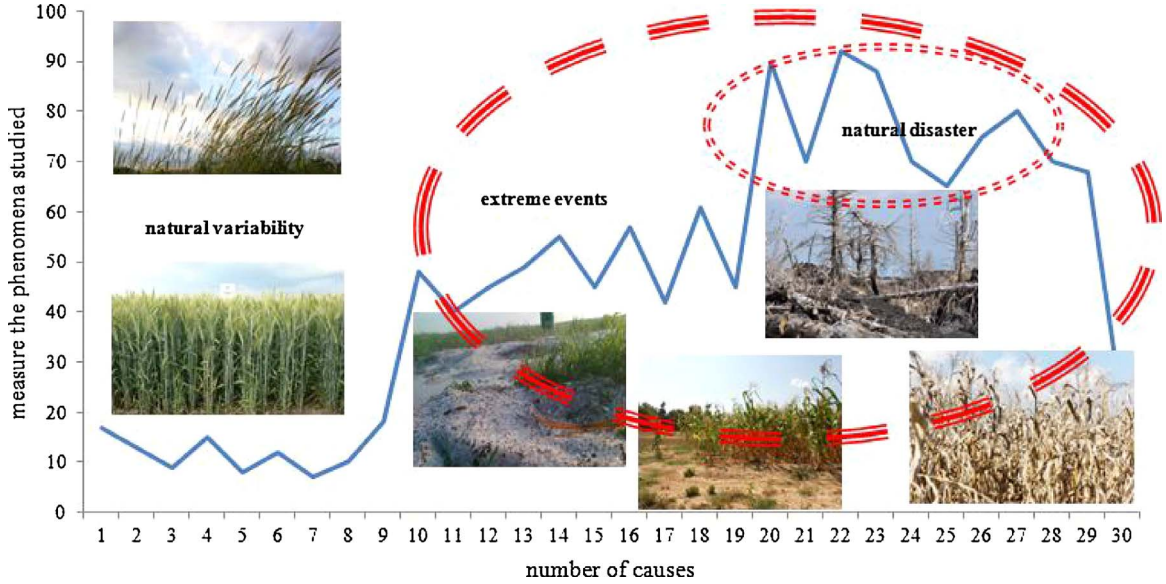



**Fig. 3.** Variability of the impact of weather events.
Source: own study.

**Table 2**
Financial losses to crops caused by extreme weather events in the part of Euroregion Baltic.
Source: own study.

| years | Rainstorm | Hail | Cyclones | Lightning Strike | Flood | Spring Frost | Drought | The negative effects of over-wintering of crops | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 1,733,733 | 144,689 | | | | | | 619,722 | 1,878,422 | 12.7 |
| 2011 | | 665,065 | | | 46,790 | 346,884 | 4,966,711 | 188,565 | 6,025,450 | 31.5 |
| 2012 | 540,607 | 2,759,144 | 187,745 | 505,320 | 74,842 | | | 4,488,605 | 4,067,658 | 43.4. |
| 2013 | 323,018 | 375,228 | 9423 | | 17,327 | | | 41,140 | 724,995 | 3.9 |
| 2014 | | 101,087 | 59,380 | 3581 | | 1,432,418 | | 69,582 | 1,596,466 | 8.5. |
| Total | 2,597,357 | 4,045,213 | 256,547 | 508,902 | 138,959 | 1,779,302 | 4,966,711 | 5,407,615 | 14,292,991 | |
| (%) | 13.2 | 20.5 | 1.3 | 2.6 | 0.8 | 9.0 | 25.2 | 27.4 | | 100 |

## 3. Methodological framework

### 3.1. The model

Network analyses have also been applied in other aspects on the research into changing climate especially their effects extreme weather events, e.g. the development of a prediction scheme of extreme rainfall event (Marwan and Kurths, 2015), the research into the number of investigated extreme events (Zscheischler et al., 2014), and the comparison of the distribution of earthquakes, floods and tsunami (Geist and Parsons, 2013). In contrast to well-known examples of complex networks, such as social (Vallacher and Nowak, 1999) or terrorist groups (Krebs, 2002), power grids (Bendyk, 2004), where the nodes are clearly defined by humans or power generating stations, here the first step of the complex network approach can be interpreted as a very flexible way to discretise a complex system. The effects of occurring extreme weather events in the area under study were integrated into a complex system. Natural systems situated in rural areas are closely interdependent structures. Adverse changes occurring in one location, e.g. a reduction in the area of forested land or the contamination of soil, water, or the air, bring about effects in a neighbouring location. There is synergy between particular elements present in the space, which may result in the establishment of various, more or less favorable systems. Agricultural area under cultivation including inhabited areas, forests, rivers, lakes, marshes and the terrain comprise a system of relationships affecting the environment, human lives, crop cultivation, etc. The agriculture and forestry sectors, using approx. 90% of the land in Europe, are dependent on natural conditions. This interdependence of environmental determinants provides a basis for an assumption that the locations in which financial losses are noted due to the occurrence of extreme weather events are linked with each other. The constructed network model uses the combination of a 5-year period of accumulation of data on financial losses, 8 types of extreme events (in certain years the same event occurred several times and was taken into account in the income reduction), and 100 communes covering a part of the Euroregion Baltic. The level of financial losses was determined using the following attributes (Table 3): time interval, location, type and area of land under agricultural cultivation, plant development phase, the level of damage, forecasted crops, average prices of particular agricultural products, the amount of income reduction due to the occurrence of an extreme weather event.

Scale-free networks (model) are distinguished by the power law distribution of the totality of nodes

$$P(k) = \frac{C}{k^{\alpha}} \tag{1}$$

also known as the Pareto principle, which describes the scale-free networks when the exponent α belongs to a narrow range of values between 2.0 and 3.0. The scale-free property is of fundamental importance here and applies to the entire distribution. This is because the power law is invariant in relation to the operation of scaling the degrees of the nodes.

If the investigated correlation *P(k)* is expressed with a double logarithmic scale, it was found that the power distribution of probability is a straight line (Fronczak and Fronczak, 2009).

$$\ln\ P(k) = -\alpha \ln\ k + \ln\ C \tag{2}$$

The power distribution expressed with novel coordinates, i.e. $X = \ln k$, $Y = \ln P(k)$, becomes equivalent to a linear correlation:

$$Y = aX + b \tag{3}$$

where $a = -\alpha$ and $b = \ln C$ (Fronczak and Fronczak, 2009).

Network models enable the prediction of the behaviour of a constructed system in many various situations; moreover, where basic rules governing their evolution are known, this evolution can be affected in a certain manner. From the point of view of network topology, the difference between scale-free networks and other networks lies in the fact that all nodes do not have the same number of edges (connections), and their structure develops in a non-accidental manner. The subsequent network nodes are more likely to connect to those with more connections. Hence, the so-called centres i.e. nodes with a number of connections significantly exceeding the degrees of the majority of the other are formed. Therefore, such a system is generally resistant to random failures (Cohen et al., 2000) while being susceptible to precisely targeted attacks (Cohen et al., 2001).

## 4. Results

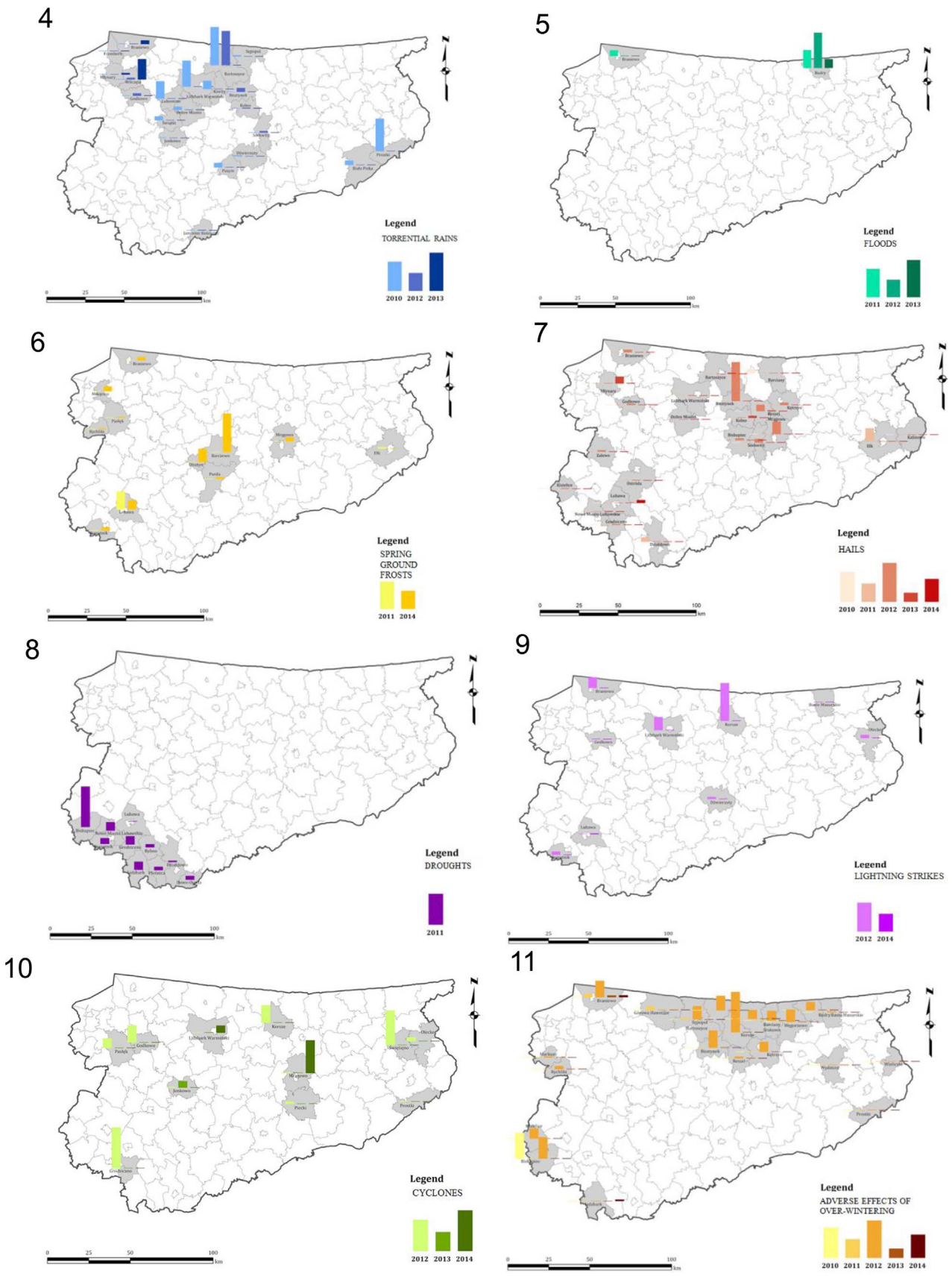
The investigated areas of the part of the Euroregion Baltic are linked by the fact that in agricultural land weather events occurred, which resulted in financial losses in agricultural farms. Each municipality/commune under analysis established a node which was described with information on the compilation of attributes (Table 3). The distribution of the nodes was examined using *Kolmogorov-Smirnov* test. This statistical method examines the null hypothesis which assumes that the distribution of variables in a sample is normal. Where the KS statistics are statistically significant ($p < 0.05$), the null hypothesis assuming the normality of variable distribution is rejected. In the area under study, the null hypothesis on the normality of distribution was rejected. In the study, the smallest square method was applied for the estimation of the characteristic exponent α. The relationship between the amount of losses and the number of units under study is presented in Fig. 12.

The investigated distribution of financial losses caused by extreme weather events in the part of the Euroregion Baltic is expressed by the following function:

$$Y = 8E + 06x^{-2.001} \tag{4}$$

with the coefficient of determination $R^2 = 0.9643$.

The adjusted linear function matches the data well, while the characteristic exponent *a* of the power function falls within the range $< 2; 3 >$, which may suggest that the investigated network is scale-free in nature. The next research step in order to verify the scale-free function was to find the logarithm of the function twice. After finding the logarithms of both sides of the equation, the line representing the distribution of nodes is a straight line, and the characteristic exponent remains constant. Fig. 13 shows the graph of the




**Figs. 4–11.** Events divided by the type along with the locations in which financial losses occurred in particular years of the study (2010–2014).
Source: own study.

**Table 3**
Attributes under study.
Source: own study.

| | Attributes | Description |
|---|---|---|
| 1 | Location of land under agricultural cultivation | Address, location in a commune under study |
| 2 | The area of land under agricultural cultivation | ha |
| 3 | Type of agricultural cultivation | Broken down into groups of crop plants |
| 4 | Plant development phase | Broken down into plant development phases |
| 5 | The level of damage | % |
| 6 | Forecasted crops | dt/ha |
| 7 | Average prices of particular agricultural products | US$ |
| 8 | Income reduction | UE$ |

function after finding the logarithms of both sides. As can be seen, the coefficient of determination $R^2 = 0.9643$ remained at the same level, while the characteristic (exponential) exponent of the power function did not change.

The constructed network is constant in relation to the scale (after finding the logarithms of both sides of the equation), and reveals its scale-free nature.

Spatial analyses indicate that the main nodes, the so-called hubs, in the agricultural land of the Euroregion Baltic under study are the municipalities of Biskupiec Pom., Bisztynek, Bartoszyce, and Korsze (Fig. 14). Three of the mentioned municipalities, namely Bisztynek, Bartoszyce and Korsze are situated in the northern part of Warmińsko-Mazurskie Voivodeship; the municipalities border each other as well as the Land of Great Masurian Lakes. The dominant extreme events which caused financial losses there are: in the municipalities of Bisztynek and Bartoszyce – adverse effects of over-wintering, hails, and torrential rains, while in the municipality of Korsze – adverse effects of over-wintering, cyclones and lightning strikes.

The constructed system has characteristics of an evolving system, which translates into the variability in time and the variability of the nature of the occurring events. Certain nodes (municipalities/communes) will be terminated over time i.e. freed from risks and losses, but new locations will emerge in which financial losses due to the occurrence of extreme events will take on a greater significance. In turn, the characteristic of the network, which is responsible for the "low resistance" to deliberate attacks, is of key importance, as the introduction of planned adaptation measures in the most "sensitive" nodes, the so-called hubs, enables the reduction in adverse effects in the agricultural production. This will translate into a reduction in financial losses as well as other positive effects on the natural environment.

In the case of the occurrence of extreme weather events, this characteristic is of great significance as the locations vulnerable to the greatest losses will indicate a trend towards increasing the number of events and financial losses in agriculture. In the locations in which the level of financial losses (accidental nodes) is low, they will decrease and, consequently, disappear.

## 5. Discussion

Climate change has been a subject of interest of many a scientist. Projections about the possible transformation of the environment due to climate change leaves no doubt that humanity (Nelson et al., 2006) has to increase their efforts to counteract it. The constructed scenarios present probable future trajectories of interactions between, for example, land use, climate change, and the economic activities of the region, etc. Scenarios of ecosystem services are also a key tool for helping decision-makers identify potential impacts of different policy options on biodiversity and ecosystem services. The local scenarios have the potential to inform by providing a rapid and inexpensive assessment of the possible effects of drivers on the productivity of ecosystem services that are key to local people (Martinez-Harms et al., 2017). The presented article uses a network analysis which enabled the investigation into the distribution of data from the statistical perspective (a *scale-free* model), and the indication of the unusual nature of the frequency of occurrence of the phenomena under study in the nature. Most frequently, this frequency is characterised by Gaussian distribution, which means that the determined average properly describes the phenomena under study (Kocur-Bera, 2014), while financial losses due to the occurrence of extreme weather events, as shown in the analysed case study, are described by *Pareto* distribution which satisfies the power-law of scaling. Such a system has no scale, therefore the analysed locations/communes with the greatest financial losses tend to grow, and the arithmetic mean is not the proper parameter describing locations being most vulnerable to the effects of climate change. Knowledge of the evolution of the thus modeled system also enables the identification of most sensitive locations, and more importantly, it enables the interference with the subject thereof (in the analysed study, it is the area in which agricultural production is carried out). This interference may be through the use of a number of ecological services tailored to the prevailing conditions, which enable the man to affect the state of ecosystems. The constructed system has characteristics of an evolving system, which translates into the variability in time and the variability of the nature of the occurring events. This type of modelling forecasts no future and is not a predictive model, yet the knowledge obtained on

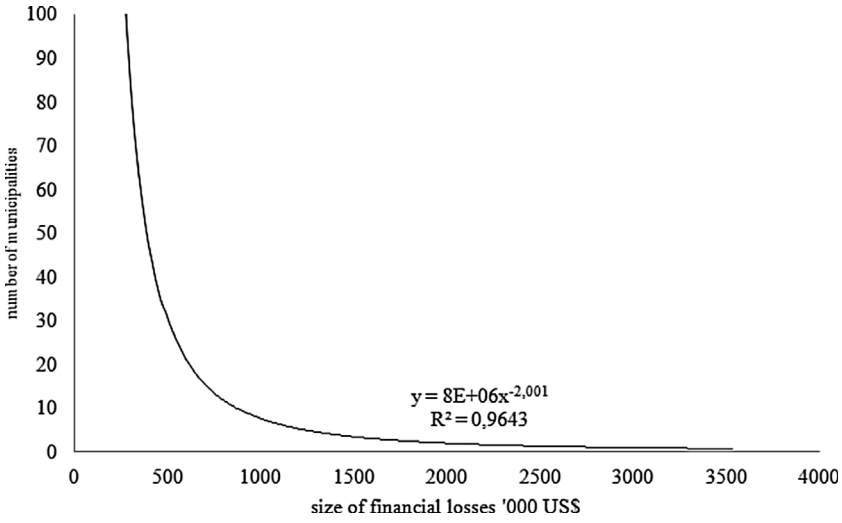



**Fig. 12.** The relationship between the amount of losses and the number of units in which those losses occurred based on data from 5 years (2010–2014), expressed in '000$.
Source: own study.

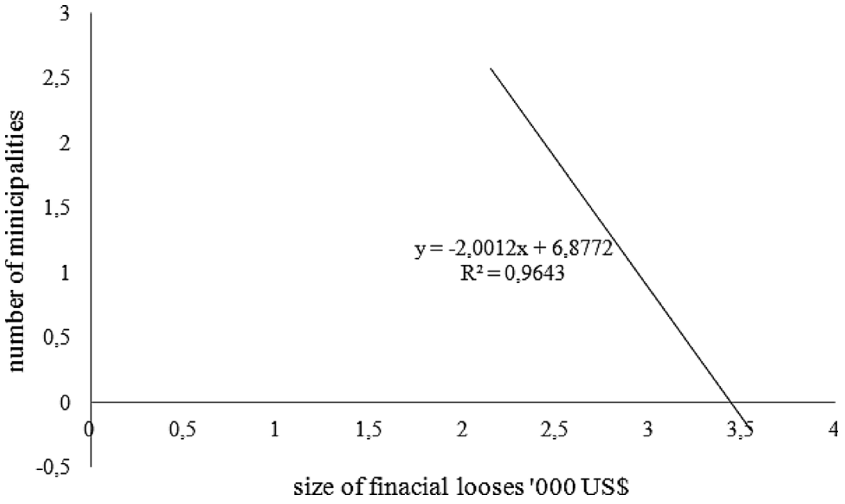



**Fig. 13.** Analysed distribution of nodes in the log–log function. Source: calculations developed using an Excel package.

the basis thereof may serve as a determinant to the introduction of changes to the use and management of rural areas, targeted in terms of location. Unlike other methods such as, for example, scenario methods, the *scale-free* model being constructed requires no adoption of assumptions about the nature of changes to the attributes affecting the model, since *in situ* data are used while modelling (Fronczak and Fronczak, 2009). The manner of modelling of variables, proposed in the article, may be used as a support for the complex, multivariate scenario analyses. This is, however, determined by the nature of the attributes under study. Knowledge of their distribution may increase the verifiability of the constructed forecasts.

### 5.1. Implications for policy and governance

The EU policy on climate change is aimed at achieving such adaptability by the States so that they are able to tackle the effects of climate change (COM, 2009). The presented model, constructed based on *in situ* studies, enables the identification of most vulnerable locations at risk of financial losses within the areas used for agricultural production in a micro-scale. The EU policy focuses on the indication of sensitive sectors (e.g. construction, health, agriculture, forestry, etc.) or locations (mountain areas, coasts, agricultural areas, etc.) but on a global scale. The constructed model allows one to identify locations being most at risk of such effects within one sector. Such a method of modelling also allows policy makers to notice the weakest points in which the financial losses may become a problem to the local

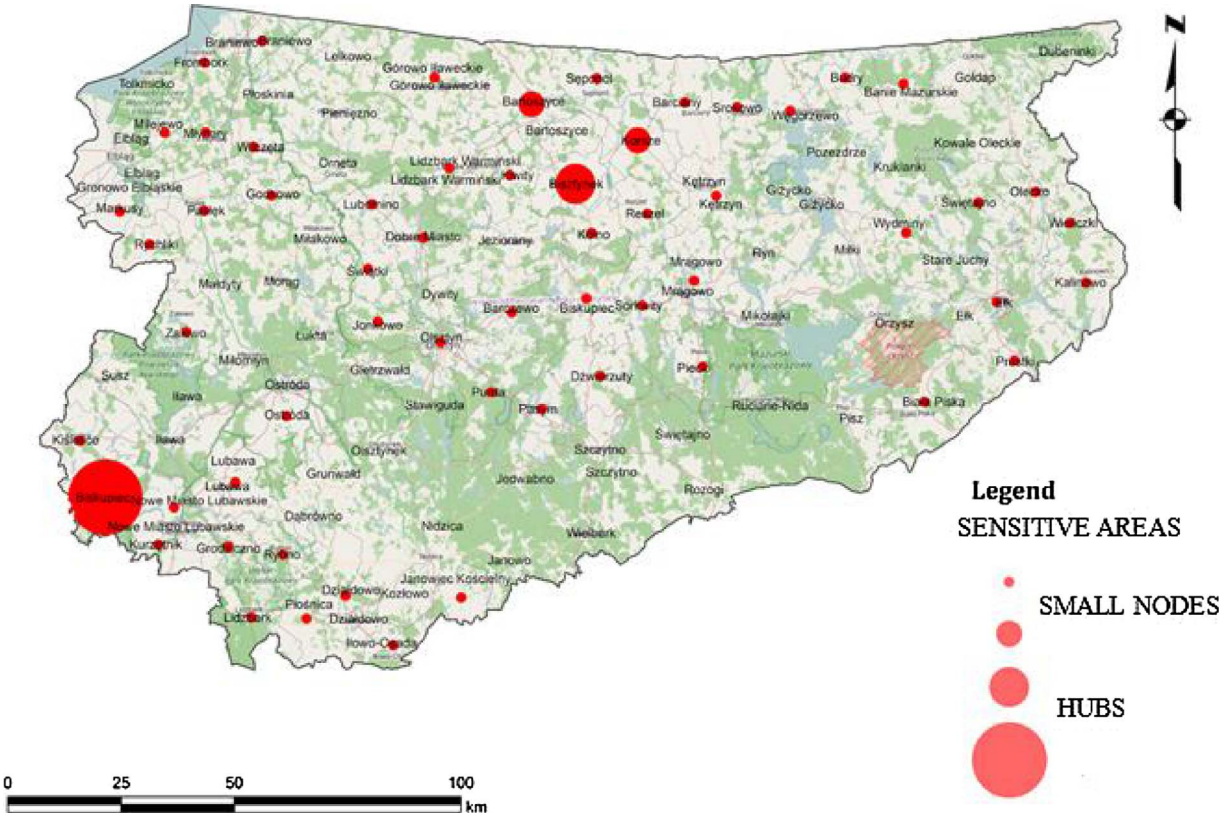



**Fig. 14.** Map showing the "centre" nodes in which the accumulation of the effects of extreme weather events. Source: own study

community. As noted by Swart et al. (2009), in order to efficiently introduce the policy for tackling climate change, it is necessary to combine actions at various territorial levels and in various spatial scales, therefore the measures taken need to be differentiated between the territorial units, and have high spatial resolution (Adger and Kelly, 1999; Cutter et al., 2000). The presented modelling method satisfies such conditions. Moreover, it makes one to have a closer look at such sensitive locations, in terms of both management of the space, patterns of its use and management, conditions for conducting agricultural production, or the occurrence of the so-called green infrastructure, and will enable the targeting of adaptation measures to take into account the local natural, spatial, economic, and social determinants. The promotion of strategies focusing on the management of water, soil, and biological resources and their protection in order to maintain and restore healthy and well-functioning ecosystems should become a priority. Studies indicate that making use of the potential of natural ecosystems as regards the counteracting and control of the effects of climate change may be an effective way of adaptation, for example biomass can function as carbon storage (Davies et al., 2011), balancing water flows to alleviate flooding (Gill et al., 2007), CO2 reduction providing thermal comfort by shading vegetation (Demuzere et al., 2014).

Surveys conducted in a group of policy makers indicate that the main barrier to the application of the strategy of maintaining and restoring healthy and well-functioning ecosystems in Poland (including in the part of the Euroregion Baltic under study) is the financial deficit, high public resistance, the lack of society's good will, and the low level of environmental awareness (Ryłko, 2015). The factors favourable to the involvement of local governments in climate policy include the competences of the local administration (Gendźwiłł, 2017), political possibilities for resolving potential conflicts, and an appropriate manner of presenting the problem for the needs of the local policy (Betsill and Bulkeley, 2007), past experience of extreme weather events, the location of a commune (in the centrally located communes, the belief that climate change needs to be dealt with, and that the local politics are effective in this regard, is more prevalent than in peripheral areas), and leaders' personal factors e.g. political views or the direction of the received education (Orderud and Kelman, 2011).

The presented model implies that as regards spatial management of the part of the Euroregion Baltic as well as the European Union, actions need to be taken in order to restore natural ecosystems, as a priority in locations being most sensitive to the phenomena under study. Currently, the functioning tools are not very effective, therefore they need to be developed by offering wider packages, projects, and other forms of financial incentives (agroecosystem services) targeted at local communities, as they reach the selected social groups most efficiently.

### 5.2. Main study limitations and future research directions

The article focuses on the modelling of financial losses due to the occurrence of extreme weather events in rural areas of the part of the Euroregion Baltic. The main aim was to indicate the locations in space with are most sensitive to the occurring natural phenomena, *inter alia* rainstorm, hail, cyclones, lightning strike, flood, spring frost, drought, and the negative effects of over-wintering of crops. Knowledge of the location of the so-called "hubs" enables the observation of prevailing natural and agricultural ecosystems and the focusing of activities which may mitigate the effects of ongoing climate change. The constructed model has scale-free features, which means that the identified greatest nodes will develop to an unpredicted scale. This can be changed by purposeful measures and activities, in particular by the application of adaptation measures, especially those restoring natural ecosystems.

The construction of the *scale-free* network model was based on *in situ* data. The data are gathered for the purpose of granting loans for resuming the production, and the restoration of the occupancy of destroyed or damaged farm buildings, tractors and agricultural machinery, and perennial plantations (so called "disaster loan"). The time constraint results from the lack of access to reliable, data being the subject matter of the analysis. By the year 2010, such information was collected for the region under study to a limited extent, and was based on approximate estimates, as no legal tools obliging to accumulate it existed. In 2010, the Council of Ministers in Poland adopted the position on the European Commission's White Paper − Adapting to climate change: towards a European framework for action, and approved implementing rules which laid down the terms and conditions for granting loans with aid for interest payments from governmental agencies (disaster loans). Both events obliged appropriate/relevant entities to carry out *in situ* measurements of the consequences of extreme weather events, which enabled the performance of the research presented in the article.

Limitations of the model result from the lack of reliable, registered data concerning a time horizon wider than the data for 2010–2014. The evidence of climate change should be considered in 10- or 20-year time horizons. This article is the first stage of research carried out in the field of modelling the consequences of extreme weather events in agriculture. The subsequent stages are planned to be published in 10-year cycles.

The constructed model was based on an integrated indicator – financial losses caused by extreme weather events. It was constructed based on attributes collected directly in the field, estimated data, and trends present in the region (see Table 1). All data used for modelling may be subject to measurement error (the area on which losses occurred), to estimation error (the level of damage suffered), and an error including average levels of the prices of cereals within the time interval under study. A similar situation concerns the method for estimating the exponent of a characteristic model. In this paper, we used the least squares method to estimate the characteristic exponent a. According to Fronczak and Fronczak (2009), "application of linear regression requires a lot of caution". Usually this method does not deal well with power-law distributions. Both estimated parameters and their uncertainty can be biased. This means the above-mentioned methods can be used only when the accuracy of the result is not important. However, when the accuracy of results is important, more reliable tools are required (Kocur-Bera, 2014). Such a method of precise study is presented in Clauset et al. (2009), in which maximum-likelihood fitting methods with goodness-of-fit tests based on the *Kolmogorov-Smirnov* and likelihood ratios are used.

Both elements, namely the level of errors and the selection of the method for estimating the exponent of the characteristic model have no significant effect on the obtained results. The analyses were primarily focused on investigating the nature of the network, and on identifying typical "*sensitive areas – the so-called hubs*" which differ from the other analysed nodes in terms of size. This research aim was achieved.

The presented studies are an initial phase of modelling data on the effects of extreme weather events. The system has characteristics of an evolving system, therefore having information containing a wider time horizon is likely to either confirm or change the trends indicated in this article. The next analyses will be performed in 10-year cycles in order to monitor the severity and impact of extreme weather events on the agricultural space.

## 6. Conclusions

Climate change has an increasingly severe impact on the environment and various areas of human life. This is demonstrated by both scientific research and statistics. It is most noticeable in sensitive sectors and areas dependent on natural weather conditions. According to the Report of the European Environment Agency (EEA Report, 2012), forecasts show considerable variation in Europe as regards the ability to deal with the adaptation to changing climate. As a consequence, it may have an adverse effect on the territorial cohesion, and contribute to an increase in socio-economic imbalance in Europe.

The investigated area of the part of the Euroregion Baltic is affected every year by a set of weather events resulting in financial losses. Given their scale, they cannot be classified as natural disasters. Such events in the area under study include torrential rains, cyclones, drought, adverse effects of crop overwintering, hail, or lightning strikes. Their effects have a significant influence on the daily operation of family farms by limiting the budget earmarked for, *inter alia*, the farm development, and by increasing the psychological discomfort associated with the received income. The proposed government support is not sufficient, while individual insurance packages are an instrument which is not very widespread among agricultural producers due to their high prices.

An analysis of the nature of financial losses within the area under study demonstrated that a network of relationships can be constructed for the municipalities/communes under study. The constructed network, thanks to the parameters of the characteristic exponent, could be included in the group of a scale-free nature. Such networks have a characteristic of low resistance to purposeful actions (sensitive locations), and high resistance to accidental actions. In addition, hubs have a characteristic of growing. In relation to the area under study, it can be interpreted as a tendency towards increasing the amount of financial losses in selected municipalities (the so-called "hubs"). Adaptation measures are primarily policy instruments whose task is, *inter alia*, to restore natural ecosystems and reduction in financial losses suffered by farmers.

Having a look at the local effects of ongoing climate change provides a solid base for the indication of the trend in the adaptation of agricultural practices, and the results of the assessment enable the indication of the most sensitive area.

The article presents the results of the first stage of research as the process of collecting information on financial losses (originating from *in situ* studies) is in the initial phase. The next analyses will be performed in 10-year cycles in order to monitor the severity and impact of extreme weather events on the agricultural space.

## References


Adger, W.N., Kelly, P.M., 1999. Social vulnerability to climate change and the architecture of entitlements. Mitig. Adapt. Strat. Global Change 4 (3-4), 253–266.

Albeverio, S., Jentsch, V., Kantz, H., 2006. Extreme Events in Nature and Society. Springer (ISSN 1612-3018).

Alcamo, J., Kok, K., Busch, G., Priess, J., 2008. Chapter four searching for the future of land: scenarios from the local to global scale. In: Alcamo, J. (Ed.), Environmental Futures: The Practice of Environmental Scenario Analysis. Elsevier, Amsterdam pp. 67–103.

Anon. Act of 18 April 2002 on the state of natural disaster (Journal of Laws of 2002 No 62, Item 558) (in Polish).

Bendyk, E., 2004. Antymatrix. Człowiek w labiryncie sieci. Wydawnictwo W.A.B. (in polish).

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., Palutikof, J., Schöll, R., Semmler, T., Woth, K., 2007. Future extreme events in European climate: an exploration of regional climate model projections. Clim. Change 81 (sup. 1), 71–95.

Betsill, M.M., Bulkeley, H., 2007. Looking back and thinking ahead: a decade of cities and climate change research. Local Environ. 5, 447–456.

Bryan, B.A., Crossman, N.D., 2013. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. Ecosyst. Serv. 4, 60–72.

Bryan, B.A., Nolan, M., McKellar, L., Connor, J.D., Newth, D., Harwood, T., King, D., Navarro, J., Cai, Y., Gao, L., Grundy, M., Graham, P., Ernst, A., Dunstall, S., Stock, F., Brinsmead, T.H., Harman, I., Grigg, N.J., Battaglia, M., Keating, B., Wonhas, A., Hatfield-Dodds, S., 2016. Land-use and sustainability under intersecting global change and domestic policy scenarios: trajectories for Australia to 2050. Global Environ. Change 38, 130–152.

Bryan, B.A., 2013. Incentives, land use, and ecosystem services: synthesizing complex linkages. Environ. Sci. Policy 27, 124–134. http://dx.doi.org/10.1016/j.envsci.2012.12.010.

COM, 2009. Biała Księga. Adaptacja Do Zmian Klimatu: Europejskie Ramy Działania. Bruksela, dnia 1.4.2009 (in polish).

CSO, 2016. Central Statistical Office, (Accessed: 03 May 2016).

Chisholm, R.A., 2010. Trade-offs between ecosystem services: water and carbon in a biodiversity hotspot. Ecol. Econ. 69, 1973–1987.

Clauset, A., Shalizi, C.R., Newman, M.E.J., 2009. Power-law distributions in empirical data. SIAM Rev. 51 (4), 661–703.

Cohen, R., Erez, K., ben-Avraham, D., Havlin, S., 2000. Resilience of the Internet to random breakdowns. Phys. Rev. Lett. 85, 4626.

Cohen, R., Erez, K., ben-Avraham, D., Havlin, S., 2001. Breakdown of the Internet under international attack. Phys. Rev. Lett. 86, 3682.

Crossman, N.D., Bryan, B.A., Summers, D.M., 2011. Carbon payments and low-cost conservation. Conserv. Biol. 25, 835–845.

Cutter, S.L., Mitchell, J.T., Scott, M.S., 2000. Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina. Ann. Assoc. Am. Geogr. 90 (4), 713–773.

Davies, Z., Edmondson, J., Heinemeyer, A., Leake, J., Gaston, K., 2011. Mapping an urban ecosystem service: quantifying above-ground carbon storage at a citywide scale. J. Appl. Ecol. 48 (5), 1125–1134.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manage. 146 (2014), 107–115.

EEA Report, 2012. Climate Change, Impacts and Vulnerability in Europe 2012. An Indicator-based Report. Office for Official Publications of the European Union, Luxembourg (No 12/2012, 10.2800/66071).

Ehrlich, P.R., Kareiva, P.M., Daily, G.C., 2012. Securing natural capital and expanding equity to rescale civilization. Nature 486, 68–73.

FAO, 2015. In: Scherf, B.D., Pilling, D. (Eds.), The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture Assessments, Rome availabe at http://www.fao.org/3/a-i4787e/index.html, 604 pp.

FAO, 2016. Climate Change and Food Security: Risks and Responses. (ISBN 978-92-5-108998-9, 110 pp.). www.fao.org/3/a-i5188e.pdf.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Fronczak, A., Fronczak, P., 2009. Świat sieci złożonych. Od fizyki do Internetu. Wydawnictwo Naukowe PWN (in Polish), 320 pp.

Geist, E.L., Parsons, T., 2013. Undersampling power-law size distributions: effect on the assessment of extreme natural hazards. Nat. Hazards 72 (2), 565–595. http://dx.doi.org/10.1007/s11069-013-1024-0.

Gendźwiłł, A., 2017. Zdecentralizowana adaptacja? Opinie władz lokalnych o zmianach klimatu i lokalnej polityce adaptacji do zmian klimatycznych. Studia Regionalne i Lokalne Nr 2 (68). http://dx.doi.org/10.7366/150949956802. ISSN 1509-4995, (in Polish).

Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 33 (1), 15–133. http://dx.doi.org/10.2148/benv.33.1.115. 13 March 2007, (19).

Golub, A.A., Henderson, B.B., Hertel, T.W., Gerber, P.J., Rose, S.K., Sohngen, B., 2012. Global climate policy impacts on livestock, land use, livelihoods, and food security. Proc. Natl. Acad. Sci. U. S. A. 110 (52), 20894–20899. http://dx.doi.org/10.1073/pnas.1108772109.

Gordon, L.J., Finlayson, C.M., Falkenmark, M., 2010. Managing water in agriculture for food production and other ecosystem services. Agric. Water Manage. 97, 512–519.

Goulder, L.H., Pizer, W.A., 2006. The Economics of Climate Change. (RFF DP 06-06 1616, P St. NW Washington, DC 20036 202-328-5000). www.rff.org.

Guerova, G., Jones, J., Douša, J., Dick, G., de Haan, S., Pottiaux, E., Bock, O., Pacione, R., Elgered, G., Vedel, H., Bender, M., 2016. Review of the state-of-the-art and future prospects of the ground-based GNSS meteorology in Europe. Atmos. Meas. Tech. Discuss. 9, 5385–5406. http://dx.doi.org/10.5194/amt-2016-125.

Guha-Sapir, D., Below, R., Hoyois Ph, 2017. EM-DAT: The CRED/OFDA International Disater Database. Universite Carholiqe de Louvain, Brussels, Belgium (Accessed 25 April 2016). www.emdat.be.

Harrison, P.A., Vandewalle, M., Sykes, M.T., Berry, P.M., Bugter, R., Bello, F., Feld, C.K., Grandin, U., Harrington, R., Haslett, J.R., Jongman, R.H.G., Luck, G.W., Silva, P.M., Moora, M., Settele, J., Sousa, J.P., Zobel, M., 2010. Identifying and prioritising services in European terrestrial and freshwater ecosystems. Biodivers. Conserv. 19, 2791–2821.

Havlik, P., Schneider, U.A., Schmid, E., Bottcher, H., Fritz, S., Skalsky, R., Aoki, K., De Cara, S., Kindermann, G., Kraxner, F., Leduc, S., McCallum, I., Mosnier, A., Sauer, T., Obersteiner, M., 2011. Global land-use implications of first and second generation biofuel targets. Energy Policy 39, 5690–5702.

IPCC, 2013. Summary for policymakers. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–29.

Jones, P.G., Thornton, P.K., 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environ. Sci. Policy 12 (4), 427–437.

Khodayar, S., Fosser, G., Berthou, S., Davolio, S., Drobinski, P., Ducrocq, V., Ferretti, R., Nuret, M., Pichelli, E., Richardh, E., Bock, O., 2016. A seamless weather–climate multi-model intercomparison on the representation of a high impact weather event in the western Mediterranean: hyMeX IOP 12. Q. J. R. Meteorolog. Soc. 142 (August (S1)), 433–452. http://dx.doi.org/10.1002/qj.2700.

Kocur-Bera, K., 2014. Scale-free network theory in studying the structure of the road network in Poland. Promet −Traffic Transp. 26 (3), 235–242.

Krebs, V., 2002. Mapping networks of terrorist cells. Connections 24, 43–52.

Kundzewicz, Z.W., Juda-Rezler, K., 2010. Zagrożenia Związane Ze Zmianami Klimatu. Nauka 4/2010, 69–76 (in Polish), dostęp 22.04.2016. http://www.pan.poznan.pl/nauki/N_410_10_Kundzewicz_klimat.pdf.

Kundzewicz, Z.W., Radziejewski, M., Pińskwar, I., 2006. Precipitation extremes in the changing climate of Europe. Climate Res. 31, 51–58.

Lant, C.L., Ruhl, J.B., Kraft, S.E., 2008. The tragedy of ecosystem services. Bioscience 58, 969–974.
Li, X., Dick, G., Lu, C., Ge, M., Nilsson, T., Ning, T., Wickert, J., Schuh, H., 2015. Multi-GNSS meteorology: real-time retrieving of atmospheric water vapor from BeiDou, galileo, GLONASS, and GPS observations. IEEE Trans. Geosci. Remote Sens. 53 (12), 6385–6393. http://dx.doi.org/10.1109/TGRS.2015.2438395.
Müller, C., Elliott, J., 2015. The Global Gridded Crop Model intercomparison: approaches, insights and caveats for modelling climate change impacts on agriculture at the global scale. In: Elbehri, A. (Ed.), Climate Change and Food Systems: Global Assessments and Implications for Food Security and Trade. FAO, Rome (Chapter 2, 59 pp).
Maron, M., Cockfield, G., 2008. Managing trade-offs in landscape restoration and re-vegetation projects. Appl. Ecol. 18, 2041–2049.
Martinez-Harms, M.J., Bryan, B.A., Figueroa, E., Pliscoff, P., Runting, R.K., Wilson, K.A., 2017. Scenarios for land use and ecosystem services under global change. Ecosyst. Serv. 25 (2017), 56–68.
Marwan, N., Kurths, J., 2015. Complex Network Based Techniques to Identify Extreme Events and (sudden) Transitions in Spatio-temporal Systems. (arXiv:1507.03778v1 [physics.data-an] 14 July 2015).
Measham, T.G., Preston, B.L., Smith, T.F., Brooke, C., Gorddard, R., Withycombe, G., Morrison, C., 2011. Adapting to climate change through local municipal planning: barriers and challenges. Mitig. Adapt. Strategies Global Change 16 (8), 889–909. http://dx.doi.org/10.1007/s11027-011-9301-2.
Nakicenovic, N., Lempert, R., Janetos, A., 2014. A framework for the development of new socio-economic scenarios for climate change research: introductory essay. Clim. Change 122, 351–361.
Nelson, G.C., Bennett, E., Berhe, A.A., Cassman, K., DeFries, R., Dietz, T., Dobermann, A., Dobson, A., Janetos, A., Levy, M., Marco, D., Nakicenovic, N., O'Neill, B., Norgaard, R., Petschel-Held, G., Ojima, D., Pingali, P., Watson, R., Zurek, M., 2006. Anthropogenic drivers of ecosystem change: an overview. Ecol. Soc. 11 (2), 29. ([online] URL:). http://www.ecologyandsociety.org/vol11/iss2/art29/.
Nelson, E., Sander, H., Hawthorne, P., Conte, M., Ennaanay, D., Wolny, S., Manson, S., Polasky, S., 2010. Projecting global land-Use change and its effect on ecosystem service provision and biodiversity with simple models. PLoS One 5 (12), e14327. http://dx.doi.org/10.1371/journal.pone.0014327.
Okuyama, Y., Chang, S., 2004. Modeling spatial and economic impacts of disasters. Springer. Advances in Spatial Sciencehttp://dx.doi.org/10.1007/978-3-540-24787-6.
Orderud, G.I., Kelman, I., 2011. Norwegian mayoral awareness of and attitudes towards climate change. Int. J. Environ. Stud. 5, 667–686.
Paluck, E.L., Shepherd, H., Aronow, P.M., 2015. Changing climates of conflict: a social network experiment in 56 schools. Psychol. Cognit. Sci. 113 (3), 566–571. http://dx.doi.org/10.1073/pnas.1514483113.
Paterson, S.E., Bryan, B.A., 2012. Food-carbon trade-offs between agriculture and reforestation and the efficiency of marketbased policies. Ecol. Soc. 17, 21.
Pielke Jr, R.A., 2007. Future economic damage from tropical cyclones: sensitivities to societal and climate changes. Phil. Trans. R. Soc. A 365, 2717–2729.
Power, A.G., 2010. Ecosystem services and agriculture: tradeoffs and synergies. Philos. Trans. R. Soc. B 365, 2959–2971.
Rahman, S., 2016. Impacts of climate change, agroecology and socio-economic factors on agricultural land use diversity in Bangladesh (1948–2008). Land Use Policy 50, 169.
Rothman, D.S., 2008. Chapter three a survey of environmental scenarios. In: Alcamo, J. (Ed.), Environmental Futures: The Practice of Environmental Scenario Analysis. Elsevier, Amsterdam pp. 37–65.
Rounsevell, M.D.A., Arneth, A., Alexander, P., Brown, D.G., de Noblet-Ducoudré, N., Ellis, E., Finnigan, J., Galvin, K., Grigg, N., Harman, I., Lennox, J., Magliocca, N., Parker, D., O'Neill, B.C., Verburg, P.H., Young, O., 2014. Towards decision-based global land use models for improved understanding of the Earth system. Earth Syst. Dyn. 5, 117–137.
Ryłko, E., 2015. Zmiany klimatu i przeciwdziałanie im w świadomości reprezentantów wybranych polskich miast. Raport z badań opinii społecznej w ramach projektu ADAPTCITY „Przygotowanie strategii adaptacji do zmian klimatu miasta metropolitalnego przy wykorzystaniu mapy klimatycznej i partycypacji społecznej". Instrumentu Finansowego LIFE+ oraz Narodowego Funduszu Ochrony Środowiska i Gospodarki Wodnej pp.66 (in Polish).
Swart, R.J., Biesbroek, G.R., Binnerup, S., Carter, T., Cowan, C., Henrichs, T., Loquen, S., Mela, H., Morecroft, M., Reese, M., Rey, D., 2009. Europe Adapts to Climate Change: Comparing National Adaptation Strategies. Partnership for European Environmental Research, Helsinki (no. 1. ISBN 9789521134517 − 283 p.).
Thomson, A.M., Calvin, K.V., Chini, L.P., Hurtt, G., Edmonds, J.A., Bond-Lamberty, B., Frolking, S., Wise, M.A., Janetos, A.C., 2010. Climate mitigation and the future of tropical landscapes. Proc. Natl. Acad. Sci. U. S. A. 107, 19633–19638.
Vallacher, R.R., Nowak, A., 1999. Dynamical Systems in Social Psychology. Academic Press San Diego.
Van Der Werf, E., Peterson, S., 2009. Modeling linkages between climate policy and land use: an overview. Agr. Econ. 40, 507–517.
Van Malderen, R., Brenot, H., Pottiaux, E., Beirle, S., Hermans, C., De Mazière, M., Wagner, T., De Backer, H., Bruyninx, C., 2014. A multi-site intercomparison of integrated water vapour observations for climate change analysis. Atmos. Meas. Tech. 7, 2487–2512. www.atmos-meas-tech.net/7/2487/2014/10.5194/amt-7-2487-2014.
Wiggering, H., Weißhuhnn, P., Burkhard, B., 2016. Agrosystem services: an additional terminology to better understand ecosystem services delivered by agriculture. Landscape Online 49, 1–15. http://dx.doi.org/10.3097/LO.201649.
ZWZ, 2014. Zasada Wzajemnej Zgodności (Cross-Compilance). Wydawnictwo Ministerstwo Rolnictwa i Rozwoju Wsi ISBN 978-83-63774-19-6 (in Polish), 63 pp.
Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and disservices to agriculture. Ecol. Econ. 64, 253–260.
Zhang, Y., Lindell, M.K., Prater, C.S., 2009. Vulnerability of community businesses to environmental disasters. Disasters 33, 38–57. http://dx.doi.org/10.1111/j.1467-7717.2008.01061.x.
Zscheischler, J., Reichstein, M., Harmeling, S., Rammig, A., Tomelleri, E., Mahecha, M.D., 2014. Extreme events in gross primary production: a characterization across continents. Biogeosciences 11, 2909–2924. www.biogeosciences.net/11/2909/2014/10.5194/bg-11-2909-2014.